GEOPHYSICAL RESEARCH LETTERS, VOL. 16, NO. 5, PAGES 453-455, MAY 1989

SEASONAL VARIATIONS OF VOLCANIC ERUPTION FREQUENCIES

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Abstract. Do volcanic eruptions have a tendency to occur more frequently in the months of May and June? Some past evidence suggests that they do. The present study, based on the new eruption catalogue of Simkin et al., investigates the monthly statistics of the largest eruptions, grouped according to explosive magnitude, geographical latitude, and year. At the 2σ level, no month-to-month variations in eruption frequency are found to be statistically significant. Examination of previously published month-to-month variations suggests that they, too, are not statistically significant. It is concluded that volcanism, at least averaged over large portions of the globe, is probably not periodic on a seasonal or annual time scale.

Introduction

Historically, volcanic eruptions have occurred slightly more frequently during some months of the year than during others (Kluge, 1862). Perret (1908) suspected the existence of frequency maxima near the solstices and equinoxes for Mount Vesuvius and a few other volcanoes. Wood (1917) and Jaggar (1920) later determined that molten lava surfaces in Halemaumau Crater at Kilauea Volcano have stood somewhat higher around the times of the solstices than around the times of the equinoxes. Jaggar et al. (1924) and Stearns and Macdonald (1946) also found eruptions of lava at both Kilauea and Mauna Loa to be clustered broadly around the winter solstice. Fayal in the Azores, however, preferentially erupts around the equinoxes (Mendoca Dias, 1962). Wood (1917) suggested that the Sun's seasonally changing declination induces small variations in the Earth's rate of rotation and so leads to cumulative stresses in the walls of the volcanic magma chamber that affect the flow of magma to the surface. On the other hand, Day and Allen (1925) suggested that the violent eruptions of Lassen Peak which occurred in May of 1914, 1915, and 1917 might have been phreatically caused by melt water from the preceding winters' snows. A similar theory was proposed for all high-latitude eruptions by Kluge (1862) and for Hawaiian eruptions by Green (1887) and Dana (1891). Recently, Casetti et al. (1981) have claimed higher-than-average eruption rates for Mount Etna during the months of November, March, and May, based on 65 known flank eruptions over the years 1323-1980. However, unless one is willing to accept the existence of a weak semiannual periodicity with two ill-defined maxima in the late spring and late autumn, all of these results are difficult to reconcile with each other. In fact, small number statistics can probably account for these maxima as being merely chance fluctuations.

Although it is conceivable that some individual volcanoes do show a weak seasonal effect, whereas, if many other volcanoes are averaged in, the effect might be diluted or even cancelled, a statistically clearer signal probably has to come from the use of more eruptions and therefore more volcanoes. Eggers and Decker (1969) have found that 56% of a total of 1792 eruptions began in the first half of the year, independently of geographical hemisphere. Using 189 eruptions, Hamilton (1973) obtained a similar bias, as peak eruption frequency occurred in May with possibly a minor peak in October. He explained this result with arguments much like Wood's (1917), but stressed in addition the possible effect of the annual variation in solar tidal force arising from the changing Earth-Sun distance. Lastly, Belov (1986) detected a June maximum in the monthly frequency distribution of about 4200 eruptions. All in all, the past published evidence suggests the possibility of a weak eruption maximum occurring in May or June.

Since, however, there exists just one global eruption record, the data bases are not wholly independent of each other. Moreover, the indiscriminate use of large numbers of eruptions of all magnitudes, as in the Eggers and Decker (1969) and Belov (1986) studies, does not take account of the severe incompleteness of the record at the smaller eruption magnitudes, the possible physical correlations among many of the minor eruptions, and the possible seasonal observing and reporting biases that would prefentially affect the statistics of the many minor eruptions (Simkin et al., 1981; Papadopoulos, 1987).

To circumvent these difficulties, a new study is undertaken here in which only the largest volcanic eruptions from the comprehensive, but previously unused, catalogue of Simkin et al. (1981) are utilized. This catalogue lists 5564 known eruptions that occurred between 8000 BC and AD 1980. The results of grouping the eruptions by magnitude, geographical latitude, and year, as well as the introduction of tests of statistical significance (which have not been reported in the earlier studies except by Eggers and Decker and by Casetti et al.), are investigated here in detail. The seasonal question is important because a statistically significant periodicity equal to about half a month and attributed to the lunar-solar tide has also been reported for volcanic eruptions (Johnston and Mauk, 1972; Mauk and Johnston, 1973; Mauk, 1979; Dzurisin, 1980). Furthermore, there is evidence of a weak maximum in the frequency of large earthquakes between the months of April and July (Davison, 1938; Morgan et al., 1961; McClellan, 1984), although this maximum is not found by all authors (Gutenberg and Richter, 1965, and references therein).

Data and Methods

Simkin et al. (1981) and Newhall and Self (1982) have ranked all the known volcanic eruptions according to a semiquantitatively-based Volcanic Explosivity Index (VEI). Only the biggest eruptions having VEI ≥ 3 (VEI=2 being largely a default category) are used here, although any eruption designated as being dubious by Simkin et al. is rejected. Some of the dates for VEI ≥ 4 eruptions in Newhall and Self are erroneous, and so the Simkin et al. dates are used instead. In a small number of cases, the day or even the month of the eruption is ambiguous since the activity consisted of a closely spaced succession of large eruptions. Either the first eruption or the most important eruption in such a series has been ac-

Paper number 89GL00573.

TABLE 1. Monthly Distribution of Eruptions by Latitude and VEI (1500-1980)

		n												
Latitudes	VEI	J	F	M	A	M	J	J	A	S	O	N	D	$<n> \pm <n>^{1/2}(1\sigma)$
90°S to 30°S	≥ 4	0	1	0	1	0	1	1	0	0	0	0	2	—
	≥ 3	1	3	1	3	2	1	3	1	0	1	3	5	—
30°S to 30°N	≥ 4	7	4	3	6	4	3	0	5	2	6	3	3	4 ± 2
	≥ 3	25	23	19	21	20	22	17	22	22	21	17	18	21 ± 5
30°N to 90°N	≥ 4	5	5	7	1	3	3	8	6	3	3	2	3	4 ± 2
	≥ 3	17	26	22	12	25	22	18	18	16	18	23	13	19 ± 4
All	≥ 4	12	10	10	8	7	7	9	11	5	9	5	8	8 ± 3
	≥ 3	43	52	42	36	47	45	38	41	38	40	43	36	42 ± 6

cepted for use here. The resulting time series of eruptions since AD 1500 is found to be nearly stationary for VEI$\geq$5 and roughly so for VEI=4. Although twentieth-century eruptions with VEI=3 show a marked steady increase in decadal frequency toward the present time owing to increasingly better observation and reporting of eruptions, it is unlikely that this type of nonstationarity would interfere with and bias a search for periodic cycles as short as one year or less. Accordingly, the present study makes use of all eruptions with VEI$\geq$3 over the years 1500-1980.

To investigate the month-to-month variations, only eruption initiation dates with published error estimates of less than ± 15 days are judged to be useful here. This margin of error encompasses any uncertainty about whether a date refers to the Julian calendar or the more accurate Gregorian calendar, as England and her colonies still used the Julian calendar until 1752, and Russia until 1918. All dates before October 4, 1582, however, are Julian and therefore are converted here to the Gregorian system.

Two statistical tests are employed to look for significant variations. First, the year is split up into essentially equal parts (months, seasons, or half-years). The number of n of observed eruptions in each part of the year is compared with the number $<n>$ expected for the null hypothesis of equal numbers in all parts of the year, given the total number of observed eruptions, N (Casetti et al., 1981). To a very good approximation, if $<n>$ exceeds 4, the expected 1σ fluctuation error may be taken to be $<n>^{1/2}$. Therefore, with 95% confidence (2σ level), we may reject the null hypothesis if any part of the year shows n outside the range $<n> \pm 2 <n>^{1/2}$.

The second statistical test, which was originally devised by Schuster (1897), measures the tendency of the dates of events to occur around the same time of the year. Using a phase angle ω_i (measured from the beginning of the year) for each date t_i the Schuster test proceeds by adding all N phases vectorially, and so finds a resultant vector having phase angle $\Omega = \arctan(B/A)$ and length $R = (A^2 + B^2)^{1/2}$, where

$$A = \Sigma \cos \omega_i , \qquad B = \Sigma \sin \omega_i$$

A vector longer than R will occur by chance from a set of N completely random phases with a probability $P = \exp(-R^2/N)$, for N greater than about 8. In computing ω_i, the year is taken to have 365 days, and February 29 is treated as March 1. This test has been generalized by Shlien (1972) so that one can also look for two clusterings of dates at opposite times of the year.

Results

Worldwide, the number of volcanic eruptions that occurred between 1500 and 1980 and had VEI $\geq$5 was 11 in the first half of the calendar year (January to June) and 7 in the second half (July to December). For VEI$\geq$4, the corresponding frequencies were 54 and 47, and for VEI$\geq$3 they were 265 and 236. Although the first half of the calendar year was apparently preferred, this result is not significant at the 2σ level and therefore does not really support Eggers and Decker's (1969) result.

Eruption numbers grouped according to month are listed in Table 1, where divisions are also made by range of geographical latitude and by VEI. Ignoring the slightly larger percentage differences among the lengths of the months as compared with the lengths of the half-years, one again finds no 2σ-level variations in the eruption frequencies.

Application of the Schuster test to the dates of eruptions with VEI$\geq$4 and VEI$\geq$3 yields a very high probability that the dates come from a random distribution, specifically $P > 0.50$. This is found for all three geographical latitude ranges used in Table 1, and also collectively for the whole globe. (Although there is no significant clustering date, the derived date occurs formally in the month of April or May for latitudes north of 30°N, February for latitudes south of 30°S, June for equatorial latitudes, and March or April for all latitudes taken together.)

Breaking up the geographical latitude zones into finer divisions increases the likelihood of accidentally obtaining large deviations. For example, nearly all eruptions reported from latitudes southward of 50°S occurred between November and April. The reason for this strong bias is almost certainly that Antarctica, its surrounding islands, and the southern spur of South America, though mostly uninhabited, are visited most often during the Southern Hemisphere summer. Significantly, no analogous seasonal bias is found for latitudes northward of 60°N, where all the active volcanoes are situated in permanently inhabited areas, Iceland and Jan Mayen.

To check whether or not an artificial seasonal bias occurs for large eruptions that were reported during Europe's Age of Discovery, the period from 1500 to 1700 is examined separately. All but one of these eruptions were northern or equatorial. Eruption counts in successive three-month bins (January to March, April to June, July to September, and October to December) are 27, 20, 18, and 22 for VEI ≥ 3. In addition, the semiannual eruption counts are 47 and 40 for VEI ≥ 3 (9 and 10 for VEI ≥ 4). No significant variations, therefore, emerge at the 2σ level.

Conclusion

No upward or downward deviations from the mean count that are as high as the 2σ level occur in the semiannual and monthly frequencies of large eruptions that represent significant portions of the globe during the time period 1500-1980. The small statistical fluctuations that do occur, however, resemble those found by Hamilton (1973) and Belov (1986), who used different eruption catalogues and different sampling procedures. If the same criteria for statistical significance that were adopted here are applied to Hamilton's and Belov's results, the weak apparent biases that they found disappear at the 2σ level. It is concluded that global volcanism is probably not periodic on time scales from two months to a year. For some individual volcanoes, however, weak seasonal or annual periodicities could exist; this question requires further study.

Acknowledgements. S. Self provided some unpublished information about the eruption catalogs and M.R. Rampino supplied two useful references.

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(Received October 20, 1988;
accepted March 13, 1989.)